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Motivations, monitoring technologies, and pay for performance[☆]

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A B S T R A C T

Monitoring technologies and pay for performance (PFP) contracts are becoming popular solutions to improve public services delivery. Their track record is however mixed. To show why this may be the case, this paper develops a principal agent model where agents' motivations vary and so the effectiveness of monitoring technologies. In such a set-up, it shows that: (i) monitoring technologies should be introduced only if agents' motivations are poor; (ii) optimal PFP contracts are non-linear/non-monotonic in agents' motivations and monitoring effectiveness; (iii) investments aimed at improving agents' motivations and monitoring quality are substitutes when agents are motivated, complements other-wise; (iv) if the agents' "type" is private information, the more and less motivated agents could be separated through a menu of PFP/non-PFP contracts, designed in a way that only the less motivated ones choose the PFP.

1. Introduction

In the last two decades, governments across the world have invested massively in monitoring and reporting technologies to improve the quality of public service delivery. The idea that such technologies promote efficiency gained increasing consensus in managerial circles, and it quickly spread to private companies and multilateral organizations.¹

But what are the channels through which monitoring and reporting technologies contribute to an improvement in public sector performance and to the provision of better services? According to the New Public Management (NPM hereinafter) school, the road to efficiency is paved by the three "Ms": markets, managers and measurement (Ferlie et al., 1996); and

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¹ For instance, at the World Bank increased attention is being paid on "deliverology," that is, on how to maximize the developmental impact of the different programs by taking into account the incentives of the different stakeholders.

measurement is what markets and managers have to rely upon to be able to exert control and enforce pay for performance (PFP hereinafter) contracts.² While a lot has been written on the effects of the introduction of PFP on the productivity of public sector organizations (Frey et al., 2013; Moynihan and Pandey, 2010; Weibel et al., 2010), much less has been written on the impact of investments made to increase measurability in public sector PFP schemes. This is quite surprising when many large ICT investments have been justified on the premise that enhanced monitoring and reporting technologies are key elements to improve organizational performances (Brynjolfsson and Hitt, 2003; Dunleavy and Carrera, 2013; Garicano and Heaton, 2010).

To better understand the trade-offs associated with performance measurability, this paper provides a simple theoretical framework to analyze the channels through which monitoring and reporting technologies may (or may not) increase the effectiveness of PFP schemes. The discussion of the relationships between PFP, agents' motivations, and organization performance, in the context of public sector organization, is attracting increasing interest in the economic literature (see, among others, Dixit, 2002; Akerlof and Kranton, 2005; Besley and Ghatak, 2005, and Prendergast, 2008). This literature focuses on the impact of non-monetary incentives on agents' performances and concludes that the effects of incentives schemes on performance may be ambivalent when agents have multiple motivations.

This paper contributes to this debate considering a stylized framework in which the measurement of outcomes is costly, and the alignment between the objectives of the agents and those of the principal is only partial. In such a set up, we show that (i) it is optimal for the principal to introduce a monitoring and reporting technology only if the latter does not impose a too high burden on the agents, and/or if the agents are not sufficiently motivated; (ii) the design of an effective PFP contract is complicated, and the optimal contract is highly non linear and/or non monotonic both in agents' motivations and in the "cost" of the monitoring and reporting technology; (iii) investments aimed at improving agents' motivations and the quality of the monitoring and reporting technology are complements when agents are highly motivated and substitutes when they are not; (iv) if the agents' "type" is private information, an effective way for the principal to separate the more motivated from the less motivated agents is to offer a menu of contracts designed in a way that only the latter choose the PFP.

The above findings may shed a new light on the fierce debate on public administration reforms and on the role played by e-government investments aimed at increasing performance measurability and hence transparency and accountability of public sector organizations (Barzelay, 2001; Bertot et al., 2010; Dunleavy et al., 2005; Pina et al., 2007). On one side, NPM advocates argue that investments in technologies that increase performance measurability boost organizations' productivity by facilitating the alignment of public servants' motivations with predefined organizational objectives (Aral et al., 2012; Ba et al., 2001). NPM advocates also point at the increasing popularity of PFP and e-government projects around the world as a measure of their success.³ On the opposite side, NPM critics argue that the increasing reliance of government programs on PFP schemes is a fad driven by consulting firms, which by no means is justified by the actual record of PFP or of e-government solutions.⁴

Our own reading of the literature is that, overall, the adoption of PFP schemes and the diffusion of e-government programs in the public sector has delivered mixed outcomes. Our model, suggesting that no one-size-fits-all solution exists, may thus provide a clear rationale for why this may be the case.

Of course, we are not the first who have looked at performance measurability in a principal agent framework; our model builds upon Holmstrom and Milgrom (1991),⁵ which first suggested that if agents have to perform multiple tasks, some monitorable and some not, incentive based contracts, which (necessarily) focus on the latter, may induce agents to reallocate effort in an inefficient way. Given that most of the goals associated with the actions of public sector organizations are by nature not univocal and cannot always be planned and defined before their executions (Moore, 1995; Alford and Hughes, 2008), it is difficult to map them in performance indicators (Propper and Wilson, 2003; Behn, 1998 2003). Baker (2002), Langbein (2010), and Le Grand (2010) provide comprehensive discussions of the costs and benefits of using PFP when goals are not univocal and/or quantifiable and performance indicators are difficult to establish. However, to our knowledge, there is no contribution that discusses how investments in monitoring and reporting technologies affect the enforcement of PFP schemes in such an environment.

Our main contribution to this literature is in modeling explicitly the costs associated with the introduction of monitoring and reporting technologies – the costs of managerial attention, according to Halac and Prat (2014) – and in studying how the interaction between such costs and agents' motivations affects the optimal PFP scheme. Agents' motivations, in our view, are indeed a critical factor to take into consideration when discussing PFP. In this dimension, we build upon Dixit (2002) who emphasizes that many public sector employees (judges, teachers, doctors, social workers) may share some "idealistic or ethic purpose served by the agency" (p. 715). Starting from such a premise, Delfgaauw and Dur (2008) show that a PFP system, offering steep incentives to the more dedicated workers, may help attract them to the public sector. Our model shares some of Delfgaauw and Dur's (2008) features. However, in our set-up, performance assessment schemes detract resources from

² See Picot et al. (1996).

³ See, for instance, OECD (2005).

⁴ See, Perry et al. (2009) and Prendergast (2015) for a comprehensive discussions of the effects of PFP schemes on public sector organizations and of the reasons why performance-related pay may fail to affect their performance.

⁵ For a comprehensive survey to the theoretical and empirical work on the provision of incentives in firms, see Prendergast (1999).

the ultimate goals of the agency,⁶ and this leads us to reach the opposite conclusions, that is, PFP may end up inducing the more motivated agents to leave the organization. This phenomenon may also be seen as a reflection of tensions between intrinsic and extrinsic motivations, as in [Kreps \(1997\)](#), and [Benabou and Tirole \(2003\)](#).

Another insight of this paper, namely the fact that optimal PFP and the associated investments in monitoring and reporting technologies have to be tailored according to output measurability, is also in line with empirical evidence. [Hasnain and Pierskalla \(2012\)](#), in an up to date and comprehensive survey of the (empirical) literature, find evidence that, when tasks are simple and outcomes observable, the use of PFP is more effective; at the same time, monitoring and reporting technologies are also more valuable in supporting PFP schemes ([Ciborra, 1996](#)) both because of moral hazard (i.e., incentive) and adverse selection (i.e., sorting more able workers, [Lazear, 2000](#)) considerations. Instead, when tasks are complex and outputs difficult to measure, the introduction of PFP schemes and the use of monitoring and reporting technologies can create distortions on incentives (e.g., discouraging the most motivated workers) or foster the wrong type of sorting. This means that the decision of whether to adopt PFP schemes, their optimal design, and the decision of how much to invest in monitoring and reporting technologies should take all these effects into consideration.

A less abstract description of the kind of problems we address, and a spicier flavor of our main results, may be derived from the following two examples, one in health care and the other in education. Consider first a hospital director who wants to improve the quality of patients' care that, simplifying, depends on the number of hours doctors work and on the quality of the care they provide. Assume that hours are observable but quality not. In order to improve doctors' incentives, the director may consider linking their compensation not only to the hours they spend in the hospital, but also to the quality of the care they provide. Since the latter is not directly measurable, the hospital can set up a costly monitoring and reporting system based on the doctors' record of how they take care of each patient, and make part of the doctors' pay linked to the quality of their respective records. Of course, filling a detailed record detracts precious time from actual patients' care, so that the optimal PFP scheme should carefully weigh the monitoring and reporting system's costs and benefits.

Consider now the case of a school principal who cares about students' learning that, simplifying again, depends on the number of hours kids are taught and on the quality of teaching. As before, assume that hours are observable, but quality (of teaching) is not. In order to improve teachers' incentives to teach well, the principal may consider linking teachers' compensation to the results of a proficiency test that students are asked to take. Since the results of such a test are an imperfect measure of what kids have actually learned at school, and the preparation of such tests is costly (in terms of hours subtracted from actual teaching), we are again in the presence of trade-offs.⁷ Clearly, the more committed doctors are to patients' care, the more committed teachers are to education, the costlier the monitoring and reporting schemes – both in terms of set-up expenses and administrative effort – the larger is the deadweight loss associated with the PFP schemes. An additional cost to be taken into consideration is the one associated with the possibility that the more committed professionals may consider leaving workplaces where too much effort is devoted to costly performance measurement.⁸ These are the real world issues that our stylized model tries to address. The remaining of the paper is organized as follows: the next section presents the basic model, solves it both when “quality” is observable and when it is unobservable; it then considers the case in which for quality to be observable a costly monitoring and reporting technology has to be adopted by the agent. In Section 3, we allow the principal to invest to improve the assessment technology. In Section 4, the analysis is extended to discuss the case where agents' motivations are heterogeneous, and they are not observable by the principal. Finally, Section 5 concludes.

2. The model

Assume that an organization (the principal hereinafter) wants to maximize the success of a specific activity, the quality of education in our last example, which depends upon the contribution of two distinct but complementary components, y and q . Let y be the component that is easy to verify/contract upon, and q the one that is not. One can think of y as a quantitative component, the hours taught in the same example, and of q as a more qualitative one, the quality of teaching. Output (learning in our example) is given by qy and is non observable/contractible. We further assume that the principal, who cares about the success of the project, has a limited budget T , and he has to delegate the implementation of the activity to a “partially motivated” agent, with limited liability.

Let discuss these last assumptions one by one. The fact that the principal faces a fixed expenditure (budget) constraint reflects the public, non-profit, nature of the activities we have in mind; however such constraints can arise also in other activities (see [Bond and Gomes, 2009](#)). By partially motivated agent, we mean that she does care about the principal's objective, but she also cares about her remuneration, and she receives negative utility from the effort she devotes to the different components of the project. Finally, we assume that there is a lower bound to the remuneration the agent can receive

⁶ In the same spirit as influence/rent-seeking activities in [Inderst et al. \(2005\)](#).

⁷ [Corbett and Wilson \(1989\)](#) maintain that raising the testing stakes can increase teaching time dedicated to minimal curriculum development at the expenses of students' learning enrichment. These results are corroborated by [Firestone and Pennell \(1993\)](#) who highlight that greater emphasis on tests encourage teachers to develop practices that are adverse to the advance of student learning, given time constraints.

⁸ This may explain why US private schools, where there is no testing, may not only attract highly qualified teachers, but can also pay them lower wages than public schools where test preparation is becoming an increasing burden, see among others [Allegretto and Tojerow \(2014\)](#).

(for instance because of the existence of a legally binding minimum wage) and, to simplify the analysis, we assume that such a minimum wage is above the agent's reservation utility, so that the agent's participation constraint is never binding.

In what follows, we first present the two extreme cases, in which q is either perfectly observable or totally unobservable, and discuss the optimal remuneration schemes that the principal can offer in either case. This allows us to get a clear understanding of the distortions associated with incomplete contracting, and it facilitates the discussion of the third, most interesting, case in which q is observable, but only at a cost. In all scenarios, the principal moves first and selects the optimal (non-renegotiable) contract by backward induction. This means that the solutions we propose are subgame perfect equilibria.

As standard in the literature, we restrict our attention to linear contracts; in addition, to spare the reader the tedious algebra, in the main text we present the results in an intuitive way, and we refer the reader to Appendix for the technical details.

2.1. Observable "quality"

To set an efficiency yardstick, we assume that both y and q , are monitorable/contractible. When this is the case, the principal, who is interested in maximizing qy , offers a compensation package $\{w, k\}$, where w is the compensation⁹ per unit of y , and k the compensation per unit of q . Denoting by subscript O the observable case, the problem of the agent can be written as:

$$\underset{y,q}{\text{Max}} U_O = \alpha qy + (wy + kq) - \frac{\gamma}{2}(q + y)^2, \quad \text{subject to: } U_O \geq U^R, \quad (1)$$

where $\alpha > 0$ is a measure of the alignments between the objectives of the principal and those of the agent, $wy + kq$ the agent's remuneration, which enters linearly in the objective function, $c(q, y) = \gamma(q + y)^2/2$ is the cost of effort, and U^R is the agent's reservation utility.

We further assume that the principal faces a binding minimum wage \bar{w} , so that $wy + kq \geq \bar{w}$ and, for the sake of simplicity, that

$$U^R = \bar{w} = 0. \quad (\text{A.0})$$

This implies that the agent's participation constraint is never binding at equilibrium and that the principal is unable to extract all the surplus from the agent.¹⁰ More importantly, we impose an upper and lower bound on the cost of effort with respect to motivation, and we assume that

$$\alpha \in (\gamma, 2\gamma). \quad (\text{A.1})$$

The lower bound on the motivation parameter (*vis-à-vis* the cost of effort) insures that the problem is well behaved and that an interior solution exists. The upper bound, instead, allows us to rule out situations in which motivations are so strong that the agent is willing to work for free. Both assumptions simplify substantially the analysis and allow us to present clean comparative statics results.

Solving for (1), we obtain:

$$y_O^*(w, k) = \frac{k(\alpha - \gamma) + w\gamma}{\alpha(2\gamma - \alpha)}, \quad (2)$$

$$q_O^*(w, k) = \frac{w(\alpha - \gamma) + k\gamma}{\alpha(2\gamma - \alpha)}, \quad (3)$$

where $y_O^*(w, k)$ and $q_O^*(w, k)$ denote the optimal choices of the agent for any given compensation package $\{w, k\}$. The principal's problem can now be written as:

$$\underset{w,k}{\text{Max}} V_O = q_O^*(w, k)y_O^*(w, k), \quad \text{such that: } q_O^*(w, k)k + y_O^*(w, k)w \leq T, \quad (4)$$

the latter expression denoting the principal's budget constraint. The solution of the problem is given by:

$$w_O^* = k_O^* = \sqrt{\frac{T(2\gamma - \alpha)}{2}}, \quad (5)$$

$$y_O^* = q_O^* = \sqrt{\frac{T}{2(2\gamma - \alpha)}}, \quad (6)$$

$$V_O^* = \frac{T}{2(2\gamma - \alpha)}. \quad (7)$$

⁹ Here we remain vague about what compensation exactly means. In a market environment, it can be the price/salary paid for each of the activities delivered. In a non market environment, it can be the budget allocated to different teams.

¹⁰ To simplify notation, from now on we will thus disregard the participation constraint altogether.

Since the objective functions (of the principal and of the agent) are symmetric in y and q , when both components are contractible, the optimal compensation scheme rewards them equally, so that the effort devoted to each of them is also equalized at equilibrium.

2.2. Unobservable “quality”

We now move to the situation in which only y is observable/contractible. Designating by subscript U the unobservable case, the problem of the agent can now be written as:

$$\text{Max}_{y,q} U_U = \alpha qy + wy - \frac{\gamma}{2}(q + y)^2. \quad (8)$$

Solving for (8), one obtains

$$y_U^*(w) = \frac{\gamma w}{\alpha(2\gamma - \alpha)}, \quad (9)$$

$$q_U^*(w) = \frac{w(\alpha - \gamma)}{\alpha(2\gamma - \alpha)}, \quad (10)$$

where $q_U^*(w)$ and $y_U^*(w)$ denote the optimal choices of the agent for any given w . The problem of the principal can now be written as:

$$\text{Max}_w V_U = q_U^*(w)y_U^*(w), \quad \text{such that: } wy_U^*(w) \leq T, \quad (11)$$

but, since the budget is given and only y is contractible, the only option for the principal is to set

$$w_U^* = T/E[y_U(w)], \quad (12)$$

where E denotes the expectation operator. Assuming rational expectations, the solution of the problem is given by:

$$w_U^* = \sqrt{\frac{T\alpha(2\gamma - \alpha)}{\gamma}}, \quad (13)$$

$$y_U^* = \frac{\sqrt{T\gamma}}{\sqrt{\alpha(2\gamma - \alpha)}}, \quad (14)$$

$$q_U^* = \frac{(\alpha - \gamma)\sqrt{T}}{\sqrt{\alpha\gamma(2\gamma - \alpha)}}, \quad (15)$$

$$V_U^* = \frac{T(\alpha - \gamma)}{\alpha(2\gamma - \alpha)}. \quad (16)$$

Comparing these results with the ones in the previous section, it is immediate to verify that $y_U^* > y_0^*$, and $q_U^* < q_0^*$. When compared with the situation in which both components are contractible, the agent now overdelivers on the measurable component y , and underdelivers on the non measurable one q . Of course, the utility of the principal is lower than when both activities are contractible, and the cost of contractual incompleteness decreases with α . In fact, when α increases, the agent puts additional effort on the non measurable component even if the latter is not remunerated; this results in an increase in q_U^* , relative to y_U^* , and thus in a reduction in the distortions. This is the reason why, when α increases, given (12), the remuneration of the observable component also increases (its “supply” decreases).

2.3. Costly observable “quality”

After having briefly discussed the cases in which “quality” is either perfectly observable or totally unobservable, we are now in a position to analyze the interesting case in which, while the principal cannot observe the agent’s choice of q , he can nonetheless introduce a costly (for the agent) monitoring and reporting technology, which allows him to infer the provision of q . More precisely, we assume that the principal relies on a monitoring and reporting technology, $s = s(q, e)$, that requires an additional input, e , on the part of the agent. To keep the analysis simple, we posit that

$$s(q) = \min\{q, \beta e\}. \quad (17)$$

This means that the provision of q is fully “scored” in the monitoring and reporting technology if the agent devotes an additional effort equal to $e = q/\beta$, with $\beta > 0$, to perform a complementary activity (e.g., reporting, coaching for testing). β is thus a measure of the efficacy of the monitoring and reporting technology, the larger is β , the more efficient the technology is.

Notice that if e can be interpreted literally as the additional cost that the agent should bear to have its performance assessed, it can be more generally thought of as a measure of how effectual the monitoring and reporting technology is.

More precisely, e can be the cost of inducing the agent to invest in a (suboptimal) but contractible technology rather than in the optimal but not contractible one. Hence, in this case, the cost function becomes $c(q, y, e) = \gamma(q + y + e)^2$. Denoting by subscript C the costly observable quality case, the problem of the agent can be written as:

$$\text{Max}_{y, q, e} U_C = \alpha q y + (w y + k \min\{q, \beta e\}) - \frac{\gamma}{2}(q + y + e)^2, \quad (18)$$

which yields

$$y_C^*(w, k) = \frac{w(1 + \beta)^2 \gamma - k \beta \xi}{\alpha \beta \zeta}, \quad (19)$$

$$q_C^*(w, k) = \frac{\beta k \gamma - w \xi}{\alpha \zeta}, \quad (20)$$

$$e_C^*(w, k) = \frac{\beta k \gamma - w \xi}{\alpha \beta \zeta}, \quad (21)$$

with $\xi \equiv (1 + \beta)\gamma - \alpha\beta$, and $\zeta \equiv 2(1 + \beta)\gamma - \alpha\beta$. As before, $y_C^*(w, k)$, $q_C^*(w, k)$, and $e_C^*(w, k)$ denote the optimal choices of the agent given a compensation package $\{w, k\}$. The problem of the principal can now be written as:

$$\text{Max}_{w, k} V_C = q_C^*(w, k) y_C^*(w, k), \quad \text{such that: } w y_C^*(w, k) + k \beta e_C^*(w, k) \leq T, \quad (22)$$

which has the following solutions:

$$\begin{aligned} w_C^* &= \sqrt{\frac{T \zeta}{2(1 + \beta)}}, & w_C^* &= w_U^* = \sqrt{\frac{T \alpha (2\gamma - \alpha)}{\gamma}}, \\ k_C^* &= \sqrt{\frac{T(1 + \beta)\zeta}{2\beta^2}}, & k_C^* &= 0, \\ y_C^* &= \sqrt{T \frac{(1 + \beta)}{2\zeta}}, \quad \text{if } \beta \geq \bar{\beta}, & y_C^* &= y_U^* = \frac{\sqrt{T\gamma}}{\sqrt{\alpha(2\gamma - \alpha)}}, \quad \text{if } \beta < \bar{\beta}, \\ q_C^* &= \frac{\beta \sqrt{T}}{\sqrt{2(1 + \beta)\zeta}}, \quad (\text{or } \alpha \leq \bar{\alpha}_C); & q_C^* &= q_U^* = \frac{(\alpha - \gamma)\sqrt{T}}{\sqrt{\alpha\gamma(2\gamma - \alpha)}}, \quad (\text{or } \alpha > \bar{\alpha}_C); \\ e_C^* &= \frac{\sqrt{T}}{\sqrt{2(1 + \beta)\zeta}}, & e_C^* &= 0, \\ V_C^* &= \frac{T\beta}{2\zeta}, & V_C^* &= V_U^* = \frac{T(\alpha - \gamma)}{\alpha(2\gamma - \alpha)}, \end{aligned} \quad (23)$$

where $\bar{\beta} \equiv 4(\alpha - \gamma)\gamma/(2\gamma - \alpha)^2$, and $\bar{\alpha}_C \equiv 2\gamma((1 + \beta) - \sqrt{1 + \beta})/\beta$ denote the (same) threshold expressed respectively in terms of β , and α , above or below which the principal adopts the monitoring and reporting technology.

From a simple inspection of (23) it follows that

Result 1. *It is optimal for the principal to introduce a pay for performance scheme if, and only if: (i) the monitoring and reporting technology is efficient enough ($\beta \geq \bar{\beta}$), or (ii) the agent is not sufficiently motivated ($\alpha \leq \bar{\alpha}_C$).*

It is worth remarking that we find threshold levels of β and α below (or above) which the principal is better off not using a monitoring and reporting technology in a model in which the principal bears no costs (other than the costs associated to the remuneration of the agents) in introducing such a technology. Of course, had we assumed a fixed cost associated with the introduction of the reporting system, our results would a fortiori hold true.

To get a clear intuition of the results, it may be worth noticing that the observable and unobservable scenarios are the limit cases for the costly observable one, when β tends to infinity and zero, respectively. When β is large, the distortions associated with the introduction of the monitoring and reporting technology tend to vanish, “quality” becomes easy to observe, and this is reflected in the optimal contract. On the opposite, for sufficiently low values of β , the cost of using reporting systems is so high that it is in the interest of the principal to treat quality as non contractible. In other words, effort is costly for the agent and, thus, the introduction of a performance assessment scheme for incentive purposes is justified only when it does not detract an excessive amount of resources from the other, productive, activity. Similarly, the distortions induced by the assessment scheme are justified only if the agent is not already sufficiently committed to the goals of the organization. If she is, she will end up subtracting effort, which she would have otherwise devoted to the productive activity, to score better

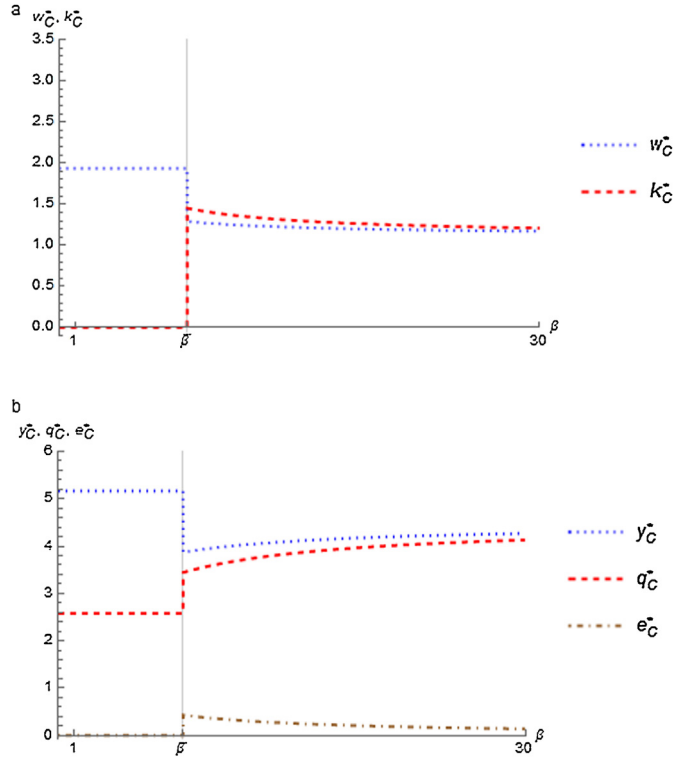


Fig. 1. Optimal compensation package and equilibrium outcomes as a function of the effectiveness of the assessment scheme, β .

in the performance assessment scheme. If these results are very intuitive, the characteristics of the optimal compensation contract are less so. In particular, using the expressions in (23), we have¹¹ that:

Result 2. *The optimal compensation scheme has the following characteristics: (i) the remuneration w , associated with the quantitative component y , is non linear in α and β , and non monotonic in α ; (ii) the remuneration k , associated with the qualitative component q , is non linear in α and β , and non monotonic in β .*

The characteristics of the optimal compensation scheme are illustrated in Figs. 1 and 2 where we plot the equilibrium value of compensation packages and the agent's activities for different values of the effectiveness of the assessment system, β , and of the agent's motivation α . More precisely, we assumed: $T = 10$; $\gamma = 0.5$; $\alpha = 0.75$ in Fig. 1, and $\beta = 10$ in Fig. 2. While the choice of T is immaterial for the results, other parameters matter. We decided to chose a value of α in the middle of the feasible interval defined in (A.1); in our (arbitrary) choice of β and γ , we just made it sure that no equilibrium outcome was ruled out.

Looking at Fig. 1a, for a given value of α , when the monitoring and reporting technology is highly distortionary (i.e., for small values of β , $\beta < \bar{\beta}$) it is better for the principal not to rely on it and set $k^* = 0$, as if effort were not contractible. When the threshold level $\bar{\beta}$ is reached, then it is optimal for the principal to adopt a performance assessment scheme. At this point, w_C^* decreases sharply and k_C^* jumps from zero to its maximum to then decrease for higher values of β . The reason for this behavior is that when the monitoring and reporting technology is relatively costly (but not so much to discourage its use) substantial monetary incentives are needed to convince the agent to bear the burden of the performance assessment scheme, a burden that decreases when the monitoring and reporting technology becomes more precise. Finally, when β becomes large enough, the distortionary effects of the performance assessment scheme tend to vanish, and the two inputs tend to be compensated in the same way.

The corresponding equilibrium levels of the different inputs are plotted in Fig. 1b. When the performance assessment scheme is highly distortionary, and only quantity is remunerated, the agent responds to the compensation scheme by overinvesting in the observable inputs y . When $\bar{\beta}$ is reached, y_C^* makes a discrete downward jump, q_C^* and e_C^* a discrete upward one. Notice that, for large values of β , e_C^* decreases and q_C^* increases reflecting the less distortionary nature of the monitoring and reporting technology.

Moving now to Fig. 2a, for any given value of β , if α is small, k_C^* is large, and it decreases continuously with α , until $\bar{\alpha}_C$, when it drops to zero and only the quantitative component is remunerated. The reason, which we already mentioned, is

¹¹ See Appendix.

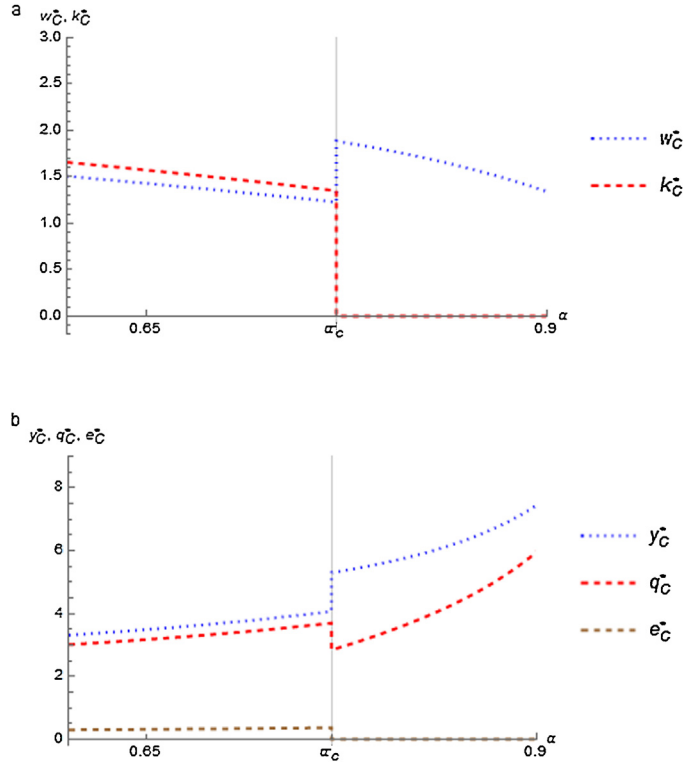


Fig. 2. Optimal compensation package and equilibrium outcomes as a function of the agent's motivation, α .

that since the introduction of the assessment scheme is distortionary, such distortions are worth bearing only if the agent is not sufficiently motivated; in the case of highly motivated agents the assessment scheme creates an unnecessary burden. The fact that k_C^* decreases with α (for $\alpha \leq \bar{\alpha}_C$) just reflects the fact that lower values of α are associated with lower output levels and higher (per unit) remuneration (w_C^* follows the same behavior). To get a better understanding of why this is the case, notice that:

$$\frac{k_C^*}{w_C^*} = 0, \quad \text{if } \beta < \bar{\beta},$$

$$\frac{y_C^*}{q_C^*} = \frac{k_C^*}{w_C^*} = \frac{1 + \beta}{\beta}, \quad \text{if } \beta \geq \bar{\beta},$$

which, in turn, implies that if the performance assessment scheme is introduced, its relative weight in the compensation package (k_C^*/w_C^*) is independent of the motivation of the agent, α , and decreases with the effectiveness of the monitoring and reporting technology (β).

The reason is that, when the performance assessment system is used, as in standard production theory, the best the principal can do is to equalize the marginal rate of technical substitution between q and y (y/q) with the (constant) economic rate of substitution between the two factors, which is equal to $1 + 1/\beta$ for the agent. To do so, in our set up (where the different inputs have the exact same cost in terms of effort), the principal has to fix the remuneration of the two activities according to the same proportion, which does not depend on α . Instead, what does depend on α is $\bar{\beta}$, the threshold value of β for which it is worth to adopt the performance assessment system. Since $\partial \bar{\beta} / \partial \alpha > 0$, when the agent is more motivated, assessment schemes that are worth implementing cannot be excessively distortionary; this is, of course, because the more motivated the agent is, the higher is the output she produces when her effort is not contractible.

Finally, it is worth mentioning that the choice of a Leontief technology for the monitoring and reporting technology simplifies the analysis greatly and allows us to find close form solutions. However, our results should hold true for more general functions. For instance, take the CES technology: $s(q) = (q^\theta + \beta e^\theta)^{1/\theta}$, if the degree of complementarity between the two inputs is large enough, the result that the principal would link compensation to the assessment scheme only if β is high enough holds true by a continuity argument.¹² What is crucial for our results to hold is that complementarity between q and e is high enough; the value added of a monitoring and reporting technology where q and e are substitute would

¹² It is well-known that a CES converges to a Leontief when $\theta \rightarrow -\infty$.

necessarily be negative. This means that finding a good monitoring and reporting technology indeed requires looking for complementarities between the unobservable inputs and what is measured in the assessment scheme.

3. Investing in technology

Until now, we have assumed that the efficiency of the monitoring and reporting technology is given, so that the only choice the principal has to undertake is whether to adopt it or not. Of course, these are quite strong assumptions, and it is interesting to see what happens in the more realistic scenario in which the principal can tailor the monitoring and reporting technology to his needs, by deciding how much to invest in its efficiency. To keep the analysis simple, we assume a linear investment technology so that the cost $g(\beta)$ of a monitoring and reporting technology with precision β is $\mu\beta$, where μ is the (constant) marginal cost of improving precision. Since the principal moves first, the problem of the agent is the same as in the previous section, and the best response functions are still given by (19)–(21). The budget constraint of the principal now becomes:

$$T = wy_C^*(w, k) + kq_C^*(w, k) - \mu\beta, \quad (24)$$

so that his problem can be written as:

$$\text{Max}_{w, k, \beta} V_{CT} = q_C^*(w, k)y_C^*(w, k), \quad \text{such that: } wy_C^*(w, k) + kq_C^*(w, k) - \mu\beta - T \leq 0. \quad (25)$$

Solving for (25), we find that if, in the previous case, the principal found it profitable to use a monitoring and reporting technology only if the latter was precise enough, now, when β is chosen optimally, what makes the difference is how costly it is to have a precise enough monitoring and reporting technology. Accordingly,¹³ we found a threshold $\bar{\mu}(T, \alpha, \gamma)$, with

$$\bar{\mu} \equiv \frac{T(2\gamma - \alpha)^3}{16\alpha(\alpha - \gamma)\gamma}, \quad (26)$$

such that if, and only if, $\mu < \bar{\mu}$ the principal finds it optimal to use the performance assessment scheme. It is worth remarking that

$$\alpha > \frac{\gamma}{2} \Rightarrow \frac{\partial \bar{\mu}}{\partial \alpha} = \frac{T(2\gamma - \alpha)^2(2\gamma^2 - 2\alpha\gamma - \alpha^2)}{16\alpha^2(\alpha - \gamma)^2\gamma} < 0, \quad (27)$$

so that, also in this case, the more motivated the agent is, the more likely it is optimal for the principal not to adopt the performance assessment scheme.

To illustrate the main results, we rely on Figs. 3–5, which are plotted using the same parametrization as in the previous section.¹⁴ The first thing that is worth noticing is that the comparative statics with respect to μ (see Fig. 3) is just the mirror image of the one with respect to β (see Fig. 1). This is not surprising at all; low marginal costs of improving the precision of the monitoring and reporting technology lead to a less distortionary performance assessment scheme. The comparative statics with respect to α (see Figs. 2 and 4) is also not affected qualitatively by the introduction of the investment decision. We now turn our attention to the determinants of the investment in the monitoring and reporting technology. If, unsurprisingly, β_C^* decreases monotonically with μ and drops to 0, when μ reaches $\bar{\mu}$ (see Fig. 5a), the relation between the investment in technology and the agent's motivations may deserve a more thorough analysis. Indeed, as we prove in Appendix and illustrate in Fig. 5b,

Result 3. *The optimal investment in the precision of the monitoring and reporting technology, β , is non monotonic in the motivations α of the agent: β increases with α until it reaches a point $\bar{\alpha}'_C$ (corresponding to $\bar{\mu}$) where it drops to zero.*

The reason for such a behavior is that, as we know from the previous analysis, with motivated agents, the only performance schemes that are worth implementing are those that involve little distortions. This means that, the more motivated an agent is, the more an additional investment in the precision of the monitoring and reporting technology is worth. This is, of course, until we reach a strong enough level of motivation for which, no matter how precise the monitoring and reporting technology, any feasible assessment scheme will just distract the agent from her duties. Assuming that an organization can invest in improving the motivations of its employees, an interesting corollary of the result above is that:

Corollary 1. *Investments aimed at improving agents' motivations and the quality of the monitoring and reporting technology are substitutes when agents are highly motivated and complements when the opposite is true.*

4. Heterogeneous agents

From the previous analysis, we concluded that the design of optimal performance schemes should be tailored according to agents' motivations, which we assumed to be known by the principal. However, usually principals do not know how

¹³ See Appendix.

¹⁴ In addition, we assumed $\mu = 0.1$ in Fig. 3a and b.

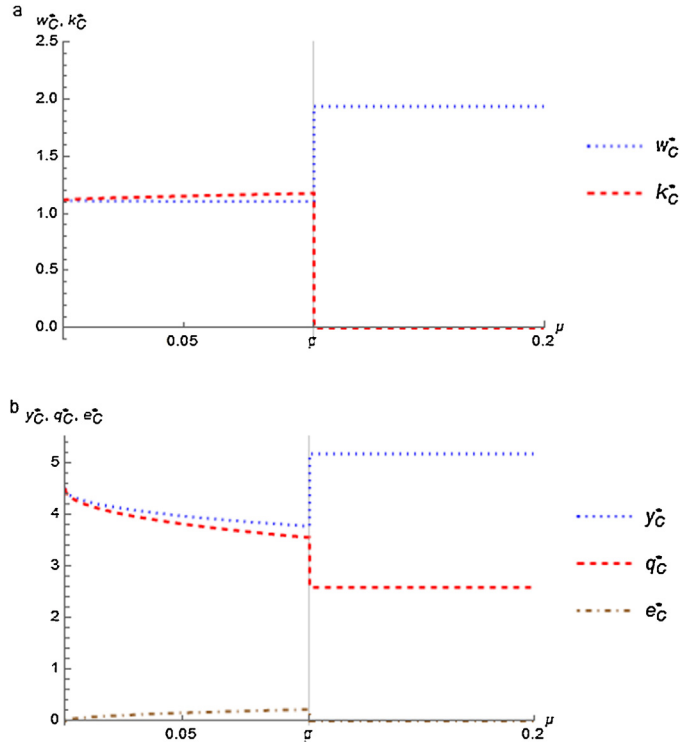


Fig. 3. Endogenous monitoring and reporting technology: optimal compensation package and equilibrium outcomes as a function of the cost of improving its precision, μ .

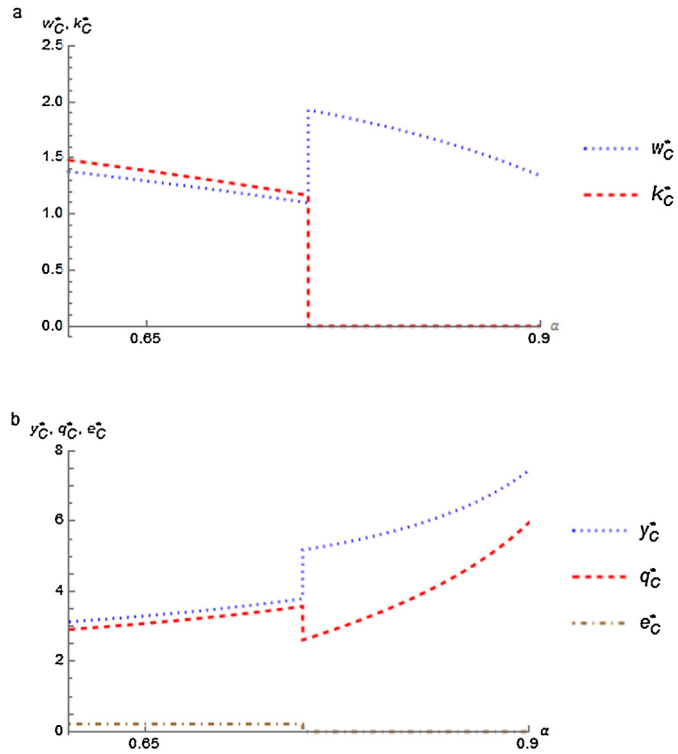


Fig. 4. Endogenous monitoring and reporting technology: optimal compensation package and equilibrium outcomes as a function of the agent's motivation, α .

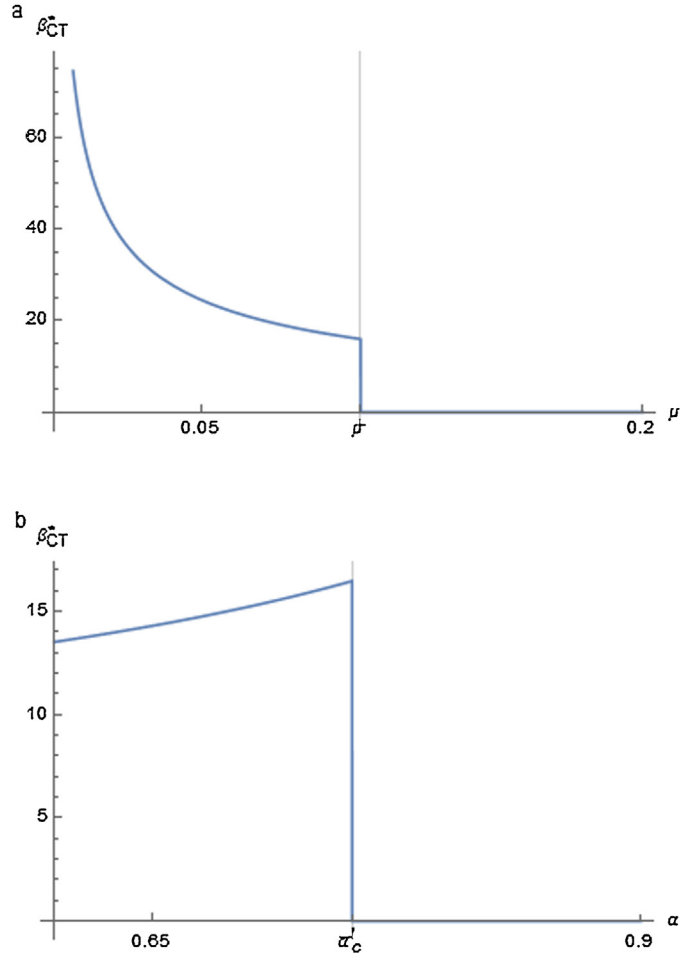


Fig. 5. Endogenous monitoring and reporting technology: optimal precision as a function of the cost of improving it, μ , and of the agent's motivation, α .

motivated agents are, and, in addition, agents tend to differ with respect to motivations. To take this into account, in this section, we extend the analysis to discuss the case where agents' motivations are heterogeneous, and they are not observable by the principal. As standard in the literature, the latter, however, knows how motivations are distributed and can offer a menu of contracts to induce agents to reveal their type and compensate them accordingly. The kind of environment we describe here could be an organization where a fraction p of agents is of type α^H (high motivated), and a fraction $(1 - p)$ is of type α^L (low motivated), with $\alpha^H > \alpha^L$. We further assume that $\alpha^L < \bar{\alpha}_C < \alpha^H$ so that a PFP contract is optimal for the low motivated agents but not for the high motivated ones. We then ask ourselves if there exists a pair of contracts $\{w^H, k^H\}$ and $\{w^L, k^L\}$, such that type α^H prefers $\{w^H, k^H\}$, type α^L prefers $\{w^L, k^L\}$, and the principal prefers this menu of contracts to any pooling contract $\{k^P, w^P\}$ that does not lead to a separation between types.

Before moving to the discussion of the separating contract, it is useful to discuss how the introduction of two different types of agents may affect the preferences of the principal for the different contracts. Assuming that the principal has a budget T , and he is forced to offer the same type of contract to all agents, we investigate the conditions under which he prefers to offer a PFP contract rather than a wage only (standard) one. If he offers a standard contract, from (9) and (10) the agents optimal response, for any given w , is given by¹⁵:

$$y_U^{i*}(w) = \frac{\gamma w}{\alpha^i(2\gamma - \alpha^i)}, \quad (28)$$

$$q_U^{i*}(w) = \frac{w(\alpha^i - \gamma)}{\alpha^i(2\gamma - \alpha^i)}, \quad (29)$$

¹⁵ With a slight abuse of notation, in this section, we use subscript \bar{U} for the wage only pooling contract (which is similar to the unobservable case discussed above), and subscript \bar{C} for the performance based pooling contract (which is similar to the costly observable case discussed above).

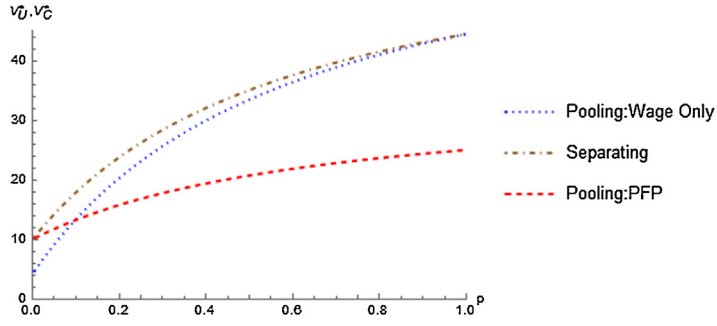


Fig. 6. Heterogeneous agents: principal's utility under pooling and separating contracts as a function of the share of motivated agents, p .

with $i \in \{L, H\}$. The problem of the principal can now be written as:

$$\text{Max}_w V_U = (1-p)q_U^{L*}(w)y_U^{L*}(w) + pq_U^{H*}(w)y_U^{H*}(w), \quad \text{such that: } (1-p)y_U^{L*}(w) + py_U^{H*}(w) \leq T. \quad (30)$$

As in the unobservable case, since the budget is given, and only y is contractible, the only option for the principal is to set

$$w_U^* = T/E[(1-p)y_U^L(w) + py_U^H(w)], \quad (31)$$

where E denotes the expectation operator. Assuming rational expectations, from (28) and (31) we have that:

$$w_U^* = \sqrt{\frac{T}{\gamma} \frac{\alpha^L \alpha^H (2\gamma - \alpha^L)(2\gamma - \alpha^H)}{(1-p)\alpha^H(2\gamma - \alpha^H) + p\alpha^L(2\gamma - \alpha^L)}}; \quad (32)$$

substituting this expression in (9) and (10) we can solve for V_U^* .

Let now consider the PFP contract, for any given $\{w, k\}$, from (19) to (21), the agents' best responses are given by:

$$y_C^{i*}(w, k) = \frac{w(1+\beta)^2\gamma - k\beta((1+\beta)\gamma - \alpha^i\beta)}{\alpha^i\beta(2\gamma(1+\beta) - \alpha^i\beta)}, \quad (33)$$

$$q_C^{i*}(w, k) = \frac{\beta k\gamma - w((1+\beta)\gamma - \alpha^i\beta)}{\alpha^i(2\gamma(1+\beta) - \alpha^i\beta)}, \quad (34)$$

$$e_C^{i*}(w, k) = \frac{\beta k\gamma - w((1+\beta)\gamma - \alpha^i\beta)}{\alpha^i\beta(2\gamma(1+\beta) - \alpha^i\beta)}. \quad (35)$$

The problem of the principal can now be written as:

$$\text{Max}_{w,k} V_C = (1-p)q_C^{L*}(w, k)y_C^{L*}(w, k) + pq_C^{H*}(w, k)y_C^{H*}(w, k), \quad (36)$$

such that:

$$T \geq w((1-p)y_C^{L*}(w, k) + py_C^{H*}(w, k)) + k((1-p)\beta e_C^{L*}(w, k) + \beta e_C^{H*}(w, k)). \quad (37)$$

Since the problem is very complex, and closed form solutions are difficult to find, we decided to carry out our analysis numerically, using the same parametrization as in the previous sections, and assuming that $\alpha^L = 0.6$ and $\alpha^H = 0.9$, two symmetric points in the feasible interval defined by (A.1), and such that $\alpha^L < \bar{\alpha}_C \approx 0.77 < \alpha^H$. In Fig. 6, we compare the utility of the principal when he offers a standard and a performance based pooling contract – as well as a separating contract, which we will discuss next – as a function of the share p of motivated agents. For the very same reasons why, in our previous discussion, we found that a PFP contract is preferred by the principal if agents are not motivated enough, now we find that this is the case if the distribution of types is “bad enough.” More precisely, we show that there is a threshold level of p , \bar{p} , such that if $p < \bar{p}$ the principal prefers the PFP contract and the standard one otherwise. In our parametrization, $\bar{p} \approx 0.1$, which implies that only when the pool of agents is “really bad” the principal will adopt a pay for performance contract.

The reason is that a pay for performance contract can be quite costly, even when the motivated agents are relatively few. This, in turn, implies that the principal may consider offering separating contracts. Among these, the most natural choice would be a menu of two contracts, a performance based $\{w^L, k^L\}$, and a wage only one $\{w^H\}$, designed in a way that the less motivated agents choose the former and the more motivated ones the latter. Before proceeding, it is important to notice that, in our simple set up if the principal knew the agents' type, he would confer the entire production to the motivated

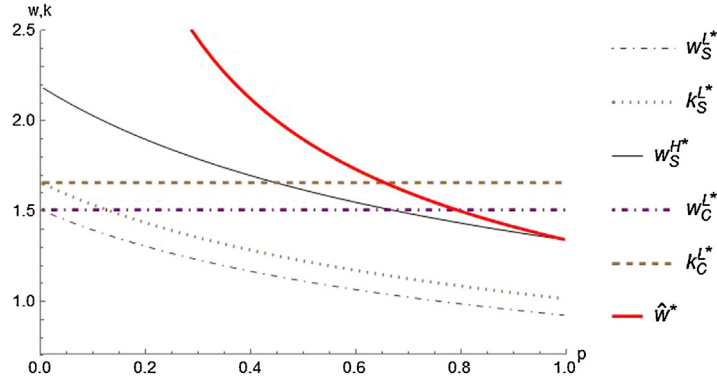


Fig. 7. Heterogeneous agents: optimal contract as a function of the share of motivated agents, p . (For interpretation of the references to color in text, the reader is referred to the web version of the article.)

agents, and the final outcome would not depend on their number.¹⁶ From (13), in this case,¹⁷ the “optimal” contract would be:

$$\hat{w}^* = \sqrt{\frac{T\alpha^H(2\gamma - \alpha^H)}{p\gamma}}. \quad (38)$$

We now move to the separating contract that we denote by subscript S . Focusing our attention on linear compensation contracts, the optimal separating contract $\{w_S^L, k_S^L; w_S^H\}$ is the solution of the following problem:

$$\max_{w_S^L, k_S^L, w_S^H} V_S = (1-p)y_{\tilde{C}}^L(w_S^L, k_S^L)q_S^L(w_S^L, k_S^L) + py_{\tilde{U}}^H(w_S^H)q_{\tilde{U}}^H(w_S^H), \quad (39)$$

such that

$$T \geq (1-p)(w_S^L y_{\tilde{C}}^L(w_S^L, k_S^L) + k_S^L \beta e_{\tilde{C}}^L(w_S^L, k_S^L)) + pw_S^H y_{\tilde{U}}^H, \quad (40)$$

$$U^H(w_S^H) > U^H(w_S^L, k_S^L), \quad (41)$$

$$U^L(w_S^L, k_S^L) > U^L(w_S^H), \quad (42)$$

where (41) and (42) represent incentive compatibility constraints of the more and less motivated agents, respectively. Of course, in this set-up, where the principal would like to pay the more motivated agents more (more so if their number is lower), the only binding incentive compatibility constraint is the one of the less motivated agent, and it is more binding the larger their number is. The solution of the problem is illustrated in Fig. 7 – while the utility level of the principal offering a separating contract (*vis-à-vis* the pooling one) is illustrated in Fig. 6.

From a simple inspection of the figure, it is evident that, in order to satisfy the less motivated agents’ participation constraint, the best the principal can do is to reduce the wage it offers to the motivated agent *vis-à-vis* the constrained optimal one given by (38). This distortion, which is equal to the difference between the (thick) red and the (thin) black line in Fig. 7, decreases with p and tends to zero when the share of motivated agents tends to one. This also implies that the utility of the principal increases with p , but it is always higher than in the case of a pooling contract, see Fig. 6. At the same time, the compensation of the less motivated agents increases with their number, as they have to make up for the lower production levels of the high motivated agents.

5. Conclusions

Tight fiscal constraints and increased awareness about “citizens’ rights” are pressing governments to find innovative solutions to reform the public administration, cutting on its costs and increasing its “value proposition.” Among these, the most popular one, advocated by NPM scholars – and NPM oriented consulting firms – is perhaps that of increasing investments in managerial and technological solutions and of rationalizing public sector organizations by increasing the accountability and transparency of their activities.

The main driver of such an agenda is the belief that an increase in the measurability of public administration activities could help addressing those incentive problems that contribute significantly to its poor performance. To get a better understanding of whether (and under which conditions) this is indeed the case, this paper develops a simple model that looks at

¹⁶ Such a result, of course, depends on the very specific functional forms we selected, but the intuition we derive here is quite general. Indeed, the smaller is the number of committed agents, the more the principal is willing to pay them so that they would be in charge of a larger share of the production.

¹⁷ Using (28) and (31) and assuming $y_{\tilde{U}}^L(w) = 0$.

the costs and benefits of using monitoring and reporting technologies to design PFP contracts in the presence of principal agents problems.

Our analysis, establishing that the decision of whether to adopt, and how to design, PFP contracts depends on the interaction between agents' motivations and the quality of the available monitoring and reporting technology, warns against one-size-fits-all solutions. More precisely, we show that managerial and technological solutions that allow measuring the effort of poorly motivated agents at a reasonable cost, and paying them accordingly, are definitively part of the solution, as NPM advocates argue. However, we also show that these solutions become part of the problem, when the contribution of the different tasks to the creation of value is difficult to measure and/or when agents are committed to the goals of the organization. In addition, our analysis contributes to the current debate by providing a framework that allows for an informed discussion of the impact that investments in monitoring and reporting technologies – such as those that drive many e-government projects – have on the effectiveness of the PFP schemes and the associated trade-offs.

These findings can help explaining the mixed results associated with NPM reforms, and they call for a more critical approach to the adoption of monitoring and reporting technologies, which pays at least as much attention to agents' commitment to public service delivery as to the “measurability” of their daily activities.

Appendix.

1. Observable “quality”

The problem of the agent is

$$\text{Max}_{y,q} U_O = \alpha q y + (w y - k q) - \frac{\gamma}{2} (q + y)^2, \quad (43)$$

with first order conditions:

$$\frac{\partial U_O}{\partial y} = (\alpha - \gamma)q - \gamma y + w = 0, \quad (44)$$

$$\frac{\partial U_O}{\partial q} = (\alpha - \gamma)y - \gamma q + k = 0. \quad (45)$$

It is immediate to verify that

$$y_O^*(w, k) = \frac{k(\alpha - \gamma) + w\gamma}{\alpha(2\gamma - \alpha)}, \quad (46)$$

$$q_O^*(w, k) = \frac{w(\alpha - \gamma) + k\gamma}{\alpha(2\gamma - \alpha)}, \quad (47)$$

solve this system. Finally, if (A.1) holds, the Hessian matrix $\begin{vmatrix} \frac{\partial^2 U_O}{\partial y^2} & \frac{\partial^2 U_O}{\partial y \partial q} \\ \frac{\partial^2 U_O}{\partial q \partial y} & \frac{\partial^2 U_O}{\partial q^2} \end{vmatrix} = \begin{vmatrix} -\gamma & \alpha - \gamma \\ \alpha - \gamma & -\gamma \end{vmatrix}$ is negative definite, so that

the second order conditions for a maximum are also verified.

The principal's problem can now be written as:

$$\text{Max}_{w,k,\lambda} V_O = q_O^*(w, k)y_O^*(w, k), \quad \text{such that: } q_O^*(w, k) + y_O^*(w, k) - T \leq 0. \quad (48)$$

Substituting (46) and (47) into (48), the associated Lagrangian problem can be written as:

$$\text{Max}_{w,k,\lambda} \mathcal{L}_O = \frac{(w(\alpha - \gamma) + k\gamma)(k(\alpha - \gamma) + w\gamma)}{(\alpha^2 - 2\alpha\gamma)^2} + \frac{(a(2kw + T\alpha) + ((k - w)^2 - 2T\alpha)\gamma)\lambda}{\alpha(\alpha - 2\gamma)}, \quad (49)$$

where λ denotes the multiplier associated with the budget constraint. The first order conditions of the problem are:

$$\frac{\partial \mathcal{L}_O}{\partial w} = \frac{2w\gamma(\alpha - \gamma - \alpha(2\gamma - \alpha)\lambda) + k(\alpha^2 - 2\alpha\gamma + 2\gamma^2 - 2\alpha(2\gamma - \alpha)(\alpha - \gamma)\lambda)}{\alpha^2(\alpha - 2\gamma)} = 0, \quad (50)$$

$$\frac{\partial \mathcal{L}_O}{\partial k} = \frac{2k\gamma(\alpha - \gamma - \alpha(2\gamma - \alpha)\lambda) + w(\alpha^2 - 2\alpha\gamma + 2\gamma^2 - 2\alpha(2\gamma - \alpha)(\alpha - \gamma)\lambda)}{\alpha^2(\alpha - 2\gamma)} = 0, \quad (51)$$

$$\frac{\partial \mathcal{L}_O}{\partial \lambda} = \frac{\alpha(T\alpha + 2k\omega) + ((k - w)^2 - 2T\alpha)\gamma}{\alpha(\alpha - 2\gamma)} = 0. \quad (52)$$

It is easy to verify that

$$w_0^* = k_0^* = \sqrt{\frac{T(2\gamma - \alpha)}{2}}, \quad (53)$$

$$\lambda_0^* = \frac{1}{2(2\gamma - \alpha)}, \quad (54)$$

solve this system. Substituting these values in (46) and (47), we have

$$y_0^* = q_0^* = \sqrt{\frac{T}{2(2\gamma - \alpha)}}. \quad (55)$$

Now, defining by g_0 , the budget constraint,

$$g_0 \equiv (kq_0^*(w, k) + wy_0^*(w, k) - T) = \frac{\alpha(T\alpha + 2k\omega) + ((k - w)^2 - 2T\alpha)\gamma}{\alpha(2\gamma - \alpha)}, \quad (56)$$

we can check that the determinant of the bordered Hessian matrix $\begin{vmatrix} 0 & \frac{\partial g_0}{\partial k} & \frac{\partial g_0}{\partial w} \\ \frac{\partial g_0}{\partial k} & \frac{\partial^2 V_0}{\partial k^2} & \frac{\partial^2 V_0}{\partial k \partial w} \\ \frac{\partial g_0}{\partial w} & \frac{\partial^2 V_0}{\partial w \partial k} & \frac{\partial^2 V_0}{\partial w^2} \end{vmatrix}$ is equal to $8kw/(\alpha^2(2\gamma - \alpha))^2$ and is positive, which is a sufficient condition for an interior maximum.

2. Unobservable “quality”

The problem of the agent can be written as

$$\text{Max}_{y,q} U_U = \alpha qy + wy - \frac{\gamma}{2}(q + y)^2, \quad (57)$$

with first order conditions:

$$\frac{\partial U_U}{\partial y} = (\gamma - \alpha)q + \gamma y - w = 0, \quad (58)$$

$$\frac{\partial U_U}{\partial q} = (\gamma - \alpha)y + \gamma q = 0. \quad (59)$$

It is easy to verify that

$$y_U^*(w) = \frac{\gamma w}{\alpha(2\gamma - \alpha)}, \quad (60)$$

$$q_U^*(w) = \frac{w(\alpha - \gamma)}{\alpha(2\gamma - \alpha)}, \quad (61)$$

solve this system. The Hessian matrix is the same as in the previous case and is negative definite, so that the second order conditions for a maximum are verified. The problem of the principal can now be written as

$$\text{Max}_w V_U = q_U^*(w)y_U^*(w), \quad \text{such that: } wy_U^*(w) \leq T, \quad (62)$$

but, since the budget is given, and only y is contractible, the only option for the principal is to set

$$w_N^* = T/E[y_U(w)]. \quad (63)$$

Assuming rational expectations, that is, $E[y_U(w)] = y_U^*(w)$, substituting (63) in (60) and solving, we have that

$$w_U^* = \sqrt{\frac{T\alpha(2\gamma - \alpha)}{\gamma}}. \quad (64)$$

Substituting now this expression into (60) and (61), we have that

$$y_U^* = \frac{\sqrt{T\gamma}}{\sqrt{\alpha(2\gamma - \alpha)}}, \quad (65)$$

$$q_U^* = \frac{(\alpha - \gamma)\sqrt{T}}{\sqrt{\alpha\gamma(2\gamma - \alpha)}}, \quad (66)$$

and thus that

$$V_U^* = \frac{T(\alpha - \gamma)}{\alpha(2\gamma - \alpha)}. \quad (67)$$

3. Costly observable “quality”

The problem of the agent is:

$$\text{Max}_{y,q,e} U_C = \alpha q y + (w y + k \min\{q, \beta e\}) - \frac{\gamma}{2}(q + y + e)^2. \quad (68)$$

Let first assume that, in equilibrium,

$$\beta e^* = q^*. \quad (69)$$

If this is the case, the problem of the agent can be written as:

$$\text{Max}_{y,q,e} \tilde{U}_C = \alpha q y + (w y + k q) - \frac{\gamma}{2} \left(q + y + \frac{q}{\beta} \right)^2, \quad (70)$$

with first order conditions:

$$\frac{\partial \tilde{U}_C^P}{\partial y} = \left(\alpha - \frac{(1+\beta)\gamma}{\beta} \right) q - \gamma y + w = 0, \quad (71)$$

$$\frac{\partial \tilde{U}_C^P}{\partial q} = \left(\alpha - \frac{(1+\beta)\gamma}{\beta} \right) y + \frac{(1+\beta)^2 \gamma}{\beta^2} q + k = 0, \quad (72)$$

which yield

$$\tilde{y}_C^*(w, k) = \frac{w(1+\beta)^2 \gamma - k\beta((1+\beta)\gamma - \alpha\beta)}{\alpha^2 \beta(2\gamma(1+\beta) - \alpha\beta)}, \quad (73)$$

$$\tilde{q}_C^*(w, k) = \frac{\beta k \gamma - w((1+\beta)\gamma - \alpha\beta)}{\alpha(2\gamma(1+\beta) - \alpha\beta)}, \quad (74)$$

$$\tilde{e}_C^*(w, k) = \frac{\beta k \gamma - w((1+\beta)\gamma - \alpha\beta)}{\alpha\beta(2\gamma(1+\beta) - \alpha\beta)}. \quad (75)$$

Finally, the Hessian matrix $\begin{vmatrix} \frac{\partial^2 \tilde{U}_C^P}{\partial y^2} & \frac{\partial^2 \tilde{U}_C^P}{\partial y \partial q} \\ \frac{\partial^2 \tilde{U}_C^P}{\partial q \partial y} & \frac{\partial^2 \tilde{U}_C^P}{\partial q^2} \end{vmatrix} = \begin{vmatrix} -\gamma & \alpha - \frac{(1+\beta)\gamma}{\beta} \\ \alpha - \frac{(1+\beta)\gamma}{\beta} & -\frac{(1+\beta)^2 \gamma}{\beta^2} \end{vmatrix}$ is negative definite if its determinant, $\alpha((2(1+\beta)\gamma/\beta) - \alpha)$, is positive, which is always the case if condition (A.1) holds, so that the second order conditions for a maximum are verified.

Substituting (73) and (74) in (70), we obtain:

$$\tilde{U}_C^*(w, k) = \frac{2kw\alpha\beta^2 + \gamma(w - \beta(w - k))^2}{2\alpha\beta(2(1+\beta)\gamma - \alpha\beta)}. \quad (76)$$

The principal's problem can now be written as

$$\text{Max}_{w,k,\lambda} \tilde{V}_C = \tilde{q}_C^*(w, k) \tilde{y}_C^*(w, k), \quad \text{such that: } \beta e_C^*(w, k) + \tilde{y}_C^*(w, k) - T \leq 0. \quad (77)$$

Substituting (73)–(75) into (77), the associated Lagrangian problem can be written as:

$$\begin{aligned} \text{Max}_{w,k,\lambda} \tilde{\mathcal{L}}_C = & \frac{(\gamma(k\beta - w(1+\beta) - w\alpha\beta)(k(\alpha\beta^2 + (1+\beta)(w - k\beta + w\beta)\gamma))}{\alpha\beta\Omega} \\ & + \frac{\Omega(k^2\beta^2\gamma + \gamma w^2(1+\beta)^2 + T(\beta\Omega + 2kw\beta(\alpha\beta - (1+\beta)\gamma)\lambda)}{\alpha\beta\Omega}, \end{aligned}$$

with first order conditions:

$$\frac{\partial \tilde{\mathcal{L}}_C}{\partial w} = \frac{w(1+\beta)^2 \Psi + k\beta\Phi}{\alpha^2 \beta \Omega^2} = 0, \quad (78)$$

$$\frac{\partial \tilde{\mathcal{L}}_C}{\partial k} = \frac{k\beta\Psi + w\Phi}{\alpha^2 \Omega^2} = 0, \quad (79)$$

$$\frac{\partial \tilde{L}_C}{\partial \lambda} = \frac{k^2 \beta^2 \gamma + w^2 (1 + \beta)^2 \gamma + T \alpha \beta (\alpha \beta - 2(1 + \beta) \gamma) + 2kw \beta (\alpha \beta - (1 + \beta) \gamma)}{\alpha \beta \Omega}, \quad (80)$$

where λ is the Lagrange multiplier associated with the budget constraint and

$$\Psi \equiv -2\gamma((2(1 + \beta)\gamma - \alpha\beta)\alpha\lambda + (1 + \beta)\gamma - \alpha\beta),$$

$$\Phi \equiv 2(1 + \beta)^2 \gamma^2 + 2\alpha^3 \beta^3 \lambda + \alpha^2 \beta (\beta - 6(1 + \beta)\gamma\lambda) + 2\alpha(1 + \beta)\gamma(2(1 + \beta)\gamma\lambda - \beta), \quad \Omega \equiv \alpha\beta - 2(1 + \beta)\gamma.$$

It is then possible to verify that

$$\tilde{w}_C^* = \sqrt{\frac{T(2(1 + \beta)\gamma - \alpha\beta)}{2(1 + \beta)}}, \quad (81)$$

$$\tilde{k}_C^* = \sqrt{\frac{T(1 + \beta)(2(1 + \beta)\gamma - \alpha\beta)}{2\beta^2}}, \quad (82)$$

$$\tilde{\lambda}_C^* = \frac{\beta}{4(1 + \beta)\gamma - 2\alpha\beta}, \quad (83)$$

solve the system (78)–(80). Substituting these values into (73)–(74), and (77) we obtain:

$$\tilde{y}_C^* = \sqrt{\frac{(1 + \beta)T}{2(2(1 + \beta)\gamma - \alpha\beta)}}, \quad (84)$$

$$\tilde{q}_C^* = \beta \sqrt{\frac{T}{2(1 + \beta)(2(1 + \beta)\gamma - \alpha\beta)}}, \quad (85)$$

$$\tilde{V}_C^* = \frac{T\beta}{2(2(1 + \beta)\gamma - \alpha\beta)}. \quad (86)$$

Now, defining by g_C the budget constraint,

$$g_C \equiv (kq_C^*(w, k) + wy_C^*(w, k) - T) = \frac{\gamma(w^2(1 + \beta)^2 + k^2\beta^2 - 2k\omega\beta((1 + \beta)\gamma - \alpha\beta) - \alpha\beta T(2(1 + \beta)\gamma - \alpha\beta))}{\alpha\beta(2(1 + \beta) - \gamma\alpha\beta)}, \quad (87)$$

we can check that the determinant of the bordered Hessian matrix $\begin{vmatrix} 0 & \frac{\partial g_C}{\partial k} & \frac{\partial g_C}{\partial w} \\ \frac{\partial g_C}{\partial k} & \frac{\partial^2 V_C}{\partial^2 k} & \frac{\partial^2 V_C}{\partial k \partial w} \\ \frac{\partial g_C}{\partial w} & \frac{\partial^2 V_C}{\partial w \partial k} & \frac{\partial^2 V_C}{\partial w^2} \end{vmatrix}$ is equal to

$(8kw\beta^2)/(\alpha^2(2(1 + \beta)\gamma - \alpha\beta)^2)$ and is positive, which is a sufficient condition for an interior maximum.

Assume now that, in equilibrium, $\beta e^* < q^*$. For this to be the case, we need that at the candidate equilibrium $\tilde{w}_C^*, \tilde{k}_C^*, \tilde{y}_C^*, \tilde{q}_C^*, \tilde{e}_C^*$, the agent has an interest in deviating by choosing (i) $e < \tilde{e}_C^*$, or (ii) $q > \tilde{q}_C^*$.

In the first case, using (68), the agent's utility at $\tilde{w}_C^*, \tilde{k}_C^*, \tilde{y}_C^*, \tilde{q}_C^*, \tilde{e}_C^* - \varepsilon$ can be written as:

$$\hat{U}_C = \alpha \tilde{y}_C^* \tilde{q}_C^* + (\tilde{w}_C^* \tilde{y}_C^* + \beta \tilde{k}_C^* (\tilde{e}_C^* - \varepsilon)) - \frac{\gamma}{2} (\tilde{q}_C^* + \tilde{y}_C^* + \tilde{e}_C^* - \varepsilon)^2. \quad (88)$$

Using (81)–(85), a necessary condition for a deviation to be profitable is that

$$\frac{\partial \hat{U}_C}{\partial \varepsilon} = \frac{(\tilde{w}_C^* (1 + \beta) + \alpha \beta \varepsilon) \gamma - 2\varepsilon (1 + \beta) \gamma^2 - \tilde{k}_C^* \beta (2\beta \gamma + \gamma - \alpha \beta)}{2(1 + \beta) \gamma - \alpha \beta} > 0. \quad (89)$$

In addition, since

$$\frac{\partial^2 \hat{U}_C}{\partial \varepsilon^2} < 0, \quad (90)$$

a necessary condition for (89) to hold is that

$$\lim_{\varepsilon \rightarrow 0} \frac{\partial \hat{U}_C}{\partial \varepsilon} = \frac{\tilde{w}_C^* (1 + \beta) \gamma - \tilde{k}_C^* \beta (2\beta \gamma + \gamma - \alpha \beta)}{2(1 + \beta) \gamma - \alpha \beta} > 0, \quad (91)$$

or

$$\tilde{k}_C^* < \frac{\tilde{w}_C^* (1 + \beta) \gamma}{\beta (2\beta \gamma + \gamma - \alpha \beta)}. \quad (92)$$

Using (82), (92), can be written as:

$$\frac{(2\gamma - \alpha)\sqrt{(1 + \beta)T(2(1 + \beta)\gamma - \alpha\beta)}}{\sqrt{2}(2\beta\gamma + \gamma - \alpha\beta)} < 0, \quad (93)$$

a contradiction, given (A.1).

In the second case, again, using (68), the agent's utility at $\tilde{w}_C^*, \tilde{k}_C^*, \tilde{y}_C^*, \tilde{q}_C^* + \varepsilon, \tilde{e}_C^*$ can be written as

$$\bar{U}_C = \alpha \tilde{y}_C^* (\tilde{q}_C^* + \varepsilon) + \tilde{w}_C^* \tilde{y}_C^* + \beta \tilde{k}_C^* \tilde{e}_C^* - \frac{\gamma}{2} (\tilde{q}_C^* + \varepsilon + \tilde{y}_C^* + \tilde{e}_C^*)^2, \quad (94)$$

using (81)–(85), a necessary condition for a deviation to be profitable is that

$$\frac{\partial \bar{U}_C}{\partial \varepsilon} = \frac{(\tilde{w}_C^*(1 + \beta) + \alpha\beta\varepsilon)\gamma - 2\varepsilon(1 + \beta)\gamma^2 - \tilde{k}_C^*\beta(2\beta\gamma + \gamma - \alpha\beta)}{2(1 + \beta)\gamma - \alpha\beta} > 0. \quad (95)$$

In addition, since

$$\frac{\partial^2 \bar{U}}{\partial \varepsilon^2} < 0, \quad (96)$$

a necessary condition for (95) to hold is that

$$\lim_{\varepsilon \rightarrow 0} \frac{\partial \bar{U}_C}{\partial \varepsilon} = \frac{\tilde{w}_C^*(1 + \beta)\gamma - \tilde{k}_C^*\beta(2\beta\gamma + \gamma - \alpha\beta)}{\beta(2(1 + \beta)\gamma - \alpha\beta)} > 0 \quad (97)$$

or

$$\tilde{k}_C^* < \frac{\tilde{w}_C^*(1 + \beta)\gamma}{\beta(2\beta\gamma + \gamma - \alpha\beta)}.$$

which we just proved is never verified.

This implies that $\beta e < q$ cannot be an equilibrium. Finally, since is it never in the interest of the agent to increase e above q^*/β it is immediate to show that $\beta e^* > q^*$ can never be an equilibrium. This, in turn, implies that the solution of the problem is given by $\beta e^* = q^*$ and that

$$\begin{aligned} w_C^* &= \sqrt{\frac{T\zeta}{2(1 + \beta)}}, & w_C^* &= w_U^* = \sqrt{\frac{T\alpha(2\gamma - \alpha)}{\gamma}}, \\ k_C^* &= \sqrt{\frac{T(1 + \beta)\zeta}{2\beta^2}}, & k_C^* &= 0, \\ y_C^* &= \sqrt{\frac{T(1 + \beta)}{2\zeta}}, \quad \text{if } \beta \geq \bar{\beta} \equiv \frac{4(\alpha - \gamma)\gamma}{(2\gamma - \alpha)^2}, & y_C^* &= y_U^* = \frac{\sqrt{T\gamma}}{\sqrt{\alpha(2\gamma - \alpha)}}, \quad \text{if } \beta < \bar{\beta}, \\ q_C^* &= \frac{\beta\sqrt{T}}{\sqrt{2(1 + \beta)\zeta}}, \quad (\text{or } \alpha \leq \bar{\alpha} \equiv \frac{2\gamma((1 + \beta) - \sqrt{1 + \beta})}{\beta}), & q_C^* &= q_U^* = \frac{(\alpha - \gamma)\sqrt{T}}{\sqrt{\alpha\gamma(2\gamma - \alpha)}}, \quad (\text{or } \alpha > \bar{\alpha}); \\ e_C^* &= \frac{\sqrt{T}}{\sqrt{2(1 + \beta)\zeta}}, & e_C^* &= 0, \\ V_C^* &= \frac{T\beta}{2\zeta}, & V_C^{*P} &= V_U^* = \frac{T(\alpha - \gamma)}{\alpha(2\gamma - \alpha)}, \end{aligned}$$

where $\bar{\alpha}_C \equiv \frac{2\gamma((1 + \beta) - \sqrt{1 + \beta})}{\beta}$, $\bar{\beta} \equiv \frac{4(\alpha - \gamma)\gamma}{(2\gamma - \alpha)^2}$, and $\zeta \equiv 2(1 + \beta)\gamma - \alpha\beta$.

Finally, noticing that $\beta > \bar{\beta} \Rightarrow \zeta > 0$, it is immediate to verify that:

$$\begin{aligned}
\frac{\partial w_C^*}{\partial \alpha} &= -\frac{T\beta}{2\sqrt{2T(1+\beta)\zeta}} < 0, \\
\frac{\partial w_C^*}{\partial \beta} &= -\frac{T\alpha}{2(1+\beta)^{3/2}\sqrt{2T\zeta}} < 0, \\
\frac{\partial k_C^*}{\partial \alpha} &= -\frac{T\sqrt{(1+\beta)}}{2\sqrt{2T\zeta}} < 0, \\
\frac{\partial k_C^*}{\partial \beta} &= -\frac{T(4(1+\beta)\gamma - \alpha\beta)}{2\beta^2\sqrt{2T(1+\beta)\zeta}} < 0, \\
\frac{\partial y_C^*}{\partial \alpha} &= \frac{T^2\beta\sqrt{(1+\beta)}}{(2T\zeta)^{3/2}} > 0, \\
\frac{\partial y_C^*}{\partial \beta} &= \frac{T\alpha}{2\zeta^{3/2}\sqrt{2(1+\beta)T}} > 0, \\
\frac{\partial q_C^*}{\partial \alpha} &= \frac{T^2\beta^2}{2(T\zeta)^{3/2}\sqrt{2(1+\beta)}} > 0, \\
\frac{\partial q_C^*}{\partial \beta} &= \frac{T(4(1+\beta)\gamma - \alpha\beta)}{2\sqrt{2T}((1+\beta)\zeta)^{3/2}} > 0, \\
\frac{\partial e_C^*}{\partial \alpha} &= \frac{T^2\beta}{2(T\zeta)^{3/2}\sqrt{2(1+\beta)}} > 0, \\
\frac{\partial e_C^*}{\partial \beta} &= -\frac{T(4(1+\beta)\gamma - \alpha(1+2\beta))}{2\sqrt{2T}((1+\beta)\zeta)^{3/2}} < 0,
\end{aligned}
\quad \text{if } \beta \geq \bar{\beta},$$

$$\begin{aligned}
\frac{\partial w_C^*}{\partial \alpha} &= -\frac{T(\alpha - \gamma)}{\sqrt{T\alpha\gamma(2\gamma - \alpha)}} < 0, \\
\frac{\partial w_C^*}{\partial \beta} &= 0, \\
\frac{\partial y_C^*}{\partial \alpha} &= \frac{T^2\gamma(\alpha - \gamma)}{(T\alpha\gamma(2\gamma - \alpha))^{3/2}} > 0, \quad \text{if } \beta < \bar{\beta}, \\
\frac{\partial y_C^*}{\partial \beta} &= 0, \\
\frac{\partial q_C^*}{\partial \alpha} &= \frac{T^2\gamma^{3/2}}{(T\alpha\gamma(2\gamma - \alpha))^{3/2}} > 0, \\
\frac{\partial q_C^*}{\partial \beta} &= 0
\end{aligned}
\quad \text{(or } \alpha \leq \bar{\alpha}), \quad \text{(or } \alpha > \bar{\alpha}).$$

4. Investing in technology

The problem of the principal is to

$$\text{Max}_{w,k,\lambda,\beta} V_T = q_C^*(w, k)y_C^*(w, k) - \lambda(wy_C^*(w, k) + kq_C^*(w, k) - \mu\beta - T), \quad (98)$$

where $q_C^*(w, k), y_C^*(w, k)$ are given by (73)–(74). The first order conditions of the problem are quite cumbersome and available upon request (as the details for this section). Using Mathematica®, we can show that

$$w_T^* = \frac{\sqrt{(2(\mu + T)\gamma - T\alpha)(2(\mu + T)\gamma + \Theta)}}{\sqrt{2\mu\alpha + 4(\mu + T)\gamma}}, \quad (99)$$

$$k_T^* = \frac{((\mu + T)\gamma + \Theta)\sqrt{(\Theta - 2(\mu + T)(T\alpha - 2(\mu + T)\gamma))}}{2T\gamma\sqrt{2\mu\alpha + 4(\mu + T)\gamma}}, \quad (100)$$

$$\beta_T^* = \frac{2\mu\gamma - \Theta}{\mu(\alpha - 2\gamma)}, \quad (101)$$

with $\Theta \equiv \sqrt{2\mu\gamma(T\alpha - 2(\mu + T)\gamma)}$ solve the system of first order conditions.¹⁸ Substituting these values into the principal's objective function, we get:

$$V_T^* = \frac{4\mu\gamma - T(\alpha - 2\gamma) - \Theta}{2(\alpha - 2\gamma)^2}. \quad (102)$$

Comparing now this solution with the solution for the unobservable case, (11), we have that

$$V_{CT}^* - V_U^* = \frac{T(\alpha - 2\gamma)^2 + 4\mu\alpha\gamma - 2\alpha\Theta}{2(\alpha - 2\gamma)^2}, \quad (103)$$

¹⁸ While we have not been able to check analytically that the second order conditions for a maximum are verified, through numerical simulations we confirmed that they are for the parametrization we use in Figs. 3–5.

and

$$V_{CT}^* - V_U^* > 0 \Leftrightarrow \mu < \bar{\mu} \equiv \frac{T(2\gamma - \alpha)^3}{16\alpha(\alpha - \gamma)\gamma}. \quad (104)$$

We also implicitly define

$$\bar{\alpha}' \equiv \{\alpha : V_{CT}^* - V_U^* = 0\},$$

and we can show that $V_{CT}^* - V_U^* > 0 \Leftrightarrow \alpha < \bar{\alpha}'$.

In addition,

$$\frac{\partial \bar{\mu}}{\partial \alpha} = \frac{T(2\gamma - \alpha)^2(2\gamma^2 - 2\alpha\gamma - \alpha^2)}{16\alpha^2(\alpha - \gamma)^2\gamma} < 0 \Leftrightarrow \alpha > (\sqrt{3} - 1)\gamma$$

condition that is always verified since $\alpha > \gamma$.

Finally, to prove Result 3, it is enough to show that $\frac{\partial \beta_t^*}{\partial \alpha} = \frac{\gamma\sqrt{2(2\gamma(\mu+T)-T\alpha)}-4\sqrt{\mu\gamma((\mu+T)\gamma-T\alpha)}}{2(\alpha-2\gamma)^2\sqrt{\mu\gamma(2(\mu+T)\gamma-T\alpha)}} > 0$, which is always the case.

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